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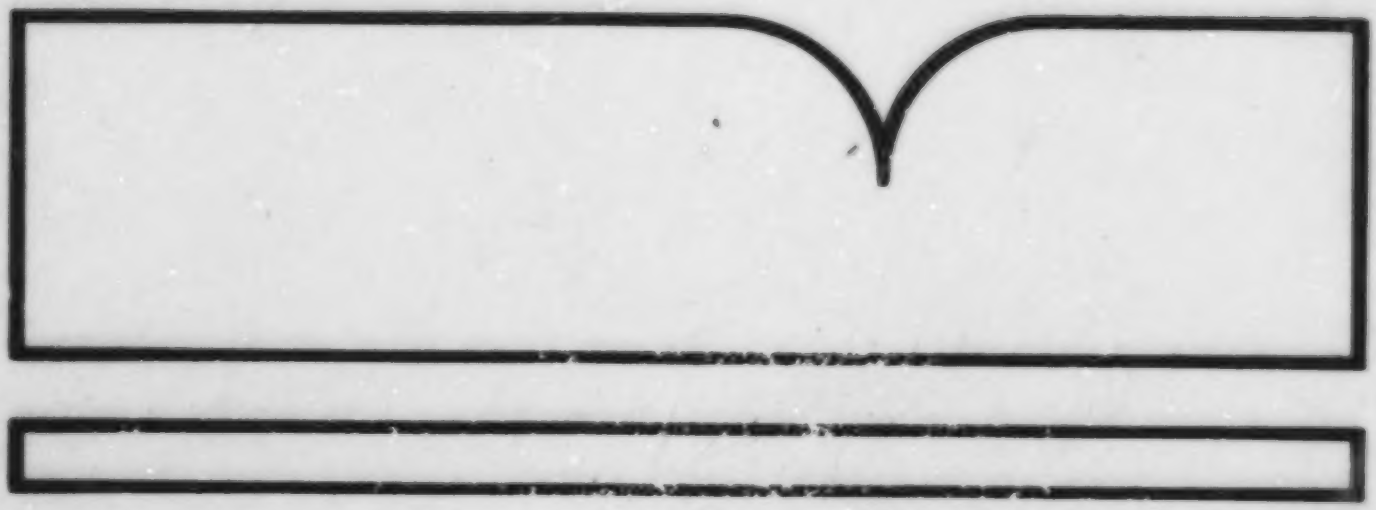

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BARRIERS TO THE TRANSMISSION OF WATERBORNE DISEASE

by

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16. ABSTRACT

The multiple barrier concept is applied by public health professionals as they attempt to prevent waterborne transmission of communicable diseases. This chapter discusses two water treatment techniques, filtration and disinfection, that are commonly used to provide barriers to disease transmission.

The portion of this work on filtration includes information on rapid rate granular media filtration, slow sand filtration, and diatomaceous earth filtration. Capabilities of these processes to reduce concentrations of viruses, bacteria, and cysts are presented. Design and operational factors that influence filter performance are discussed.

General considerations related to disinfection are given, after which the microbial inactivation capabilities of chlorine species (free and combined), chlorine dioxide, and ozone are discussed. This chapter contains information on inactivation of a variety of microorganisms, including coliforms, Giardia cysts, and poliovirus.

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BARRIERS TO THE TRANSMISSION OF WATERBORNE DISEASE

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I. INTRODUCTION

As water supply practice has evolved in the United States in the past hundred years, efforts to provide safe drinking water and prevent outbreaks of waterborne disease have focused on protection of water quality and treatment to improve water quality. The use of both water quality protection and water treatment is known as the multiple barrier concept.

The multiple barrier concept provides for measures to reduce contamination of the water source and to eliminate pathogens should they be present. Some water systems rely on barriers to protect raw water quality, but those using major river systems must rely more heavily on treatment of the water than on protection of the source. Some systems using ground water rely only on sanitary well construction and the natural protection given to the ground water, and do not disinfect. Such systems are vulnerable if the aquifer or well becomes contaminated.

The need and the opportunity for water quality protection measures can be established by conducting sanitary surveys. Water quality protection can be obtained by a great variety of techniques, including sanitary construction of wells, restriction of human activity on watersheds, treatment of wastewater, location of water works intakes upstream from pollution discharges, and cross connection control programs.

Water treatment techniques include clarification by slow sand filters, diatomaceous earth (DE) filters, or rapid rate granular (sand, dual media, or mixed media) filters, with the latter preceeded by coagulation and (usually) by flocculation and sedimentation. Disinfection in the United States is generally accomplished by use of chlorine or chloramine. Some

waters are disinfected with ozone or chlorine dioxide, or occasionally by iodine or by means of ultraviolet light.

This chapter discusses water treatment techniques and disinfection practices to prevent transmission of disease. Water quality surveillance and source protection are discussed in Chapter 9.

II. FILTRATION

Water filtration can remove a variety of particulate substances, including soil particles, algae, and microorganisms. Water filtration improves the aesthetic quality of drinking water. Properly operated water filtration plants can clarify water, making disinfection more effective, and can remove microorganisms from water, leaving fewer in the water for the disinfection barrier to inactivate. Three water filtration processes generally used are slow sand filtration, rapid sand or rapid rate granular media filtration, and diatomaceous earth filtration.

A. Process Descriptions

Slow sand filtration originated in Great Britain in the 1800's. In this process, uncoagulated water is applied to a sand bed about 1 meter deep at a filtration rate (approach velocity) of about 0.1 meter/hour (m/hr). Removal of microorganisms is aided by biological processes that occur on and in the filter bed, where an ecosystem becomes established with extended use. On the top of the media, a biologically active scum layer (schmutzdecke) builds up which assists in filtration.

As the water enters the schmutzdecke, biological action breaks down some organic matter, and inert suspended particles may be physically strained out of the water. The water then enters the top layer of sand where more physical straining and biological action occur and attachment of particles

onto the sand grain surfaces takes place. Also some sedimentation may occur in the pores between the media grains where velocity is sufficiently slow.

The filter must be drained and the top layer of sand removed, when the depth of the schmutzdecke layer increases, clogging the top sand layer and causing the headloss through the filter to reach a predetermined level. This period of scraping is the only time during normal operations in which additional manpower may be required to operate the filter. The amount of time between scrapings will depend on how much material is filtered out of the water. Thus high turbidity levels would shorten the cycle. Slow sand filter runs can be as short as one or two weeks when turbid or algae laden waters are treated. The runs can last for several months when very clear waters are filtered.

Slow sand filters are uncomplicated and easy to operate, but they can be used successfully only with a very good quality of raw water (turbidity usually less than 10 nephelometric turbidity units (NTU) and no undesirable inorganic or organic chemicals present). They also require large land areas per volume of water treated, and thus would probably be limited to use for small water systems in the United States.

About 1900, engineers in the United States began to recommend the use of rapid sand filters for treatment of muddy surface waters like those found in the Ohio River and Mississippi River valleys. These filters treat water that has been conditioned by coagulation, flocculation and sedimentation to remove most of the particulate matter and thus result in longer filter runs. Rapid sand filters typically were operated at rates of 5 m/hr in the

first half of this century. Since 1950, use of dual media (coal and sand) or mixed media (coal, sand, and garnet or ilmenite) has permitted operation of rapid rate filters at rates as high as 10 to 24 m/hr. For clear waters (10 ntu or lower) the sedimentation and sometimes flocculation processes may be omitted, and the process is known as direct filtration. In direct filtration, all removal of particulate matter occurs within the filter. Effective coagulation is essential for successful operation of rapid rate filters, with or without sedimentation.

During World War II, an intense effort was made to develop a filtration process that would give practically complete removal of Endamoeba histolytica cysts. The result was the diatomaceous earth (DE) filtration process. In DE filtration, a thin coating (3 to 5 mm) of diatomaceous earth is placed on a filter septum by recirculating filtered water that contains diatomite. After the filter cake is established in the precoating process, raw water that has been dosed with a small amount of diatomaceous earth is passed through the filter. Particles are removed, and they accumulate on the filter cake. Because DE (the body feed) is added to the raw water, the good hydraulic characteristics of the filter cake are maintained, and long filter runs can be attained. When a run is terminated, the filter cake is removed, disposed of, and fresh diatomite is used to recoat the clean septum.

Each of the filtration processes described can provide a barrier to the transmission of waterborne pathogens. The remainder of this section of the chapter describes the factors that influence the pathogen removal efficacy of the filtration processes described previously.

B. Microorganism Removal Capabilities

1. Slow Sand Filters

The ability of slow sand filters to remove bacteria from drinking water was shown first by the decline in disease and death rates for waterborne diseases such as cholera and typhoid fever in areas served by water systems employing this treatment. After appropriate microbiological methods were developed, the efficacy of slow sand filters for removal of bacteria, virus, and Giardia cysts was evaluated.

A number of factors influence the efficiency of microorganism removal by slow sand filters. Results of a number of investigations have been tabulated for purposes of comparison.

Early work by Hazen[1] and recent results from Colorado State University (CSU)[2] show that finer sand is more effective, although use of smaller sized media results in greater head loss and therefore shorter filter runs. (Table 1).

Because slow sand filtration is influenced by biological processes, the condition of the filter bed has a strong influence on removal of microorganisms, especially coliform and plate count bacteria [3 - 5] and polio virus. Virus removal by sterilized sand was negligible,[6] and virus removal by clean sand was variable, but often poor.[7] Filter scraping and schmutzdecke removal, which are done when terminal head loss is reached, have in some instances decreased bacteria removal efficiency. Research with Giardia cysts indicated that after a biological population has become established in a new sand bed, the removal of the schmutzdecke has little or no deleterious effect on removal of the cysts.[5] (Table 2). This may indicate that the cysts are more readily removed than bacteria. The need for an initial ripening period should be considered when new slow sand filters are

brought on line, as water quality will gradually improve over a period of weeks of operation.

Water temperature has an important effect on slow sand filter effluent quality. (Table 3). For the full-sized filters or very large pilot filters studied by Hazen,[3] Jordan,[8] and Pyper,[9] data are summarized by season rather than for operation at a specific temperature. Work by Poynter and Slade[10] and studies performed at Colorado State University[2,5] were done with pilot filter columns about one foot in diameter, and specific temperature data are available. Removal of all organisms has been shown to decline as temperatures decrease and biological processes slow down. If water demand permits, operation of slow sand filters at lower rates in winter than in summer would be advisable.

Although some exceptions exist, higher filtration rates generally resulted in a slight decrease in efficiency for removal of microorganisms. (Table 4). Higher filtration rates cause higher shear stresses within the pore spaces of the filter bed and reduce the time required for water to pass through the bed, thus reducing time of exposure to the ecosystem in the bed.

Evaluation of the effect of filter bed depth on microorganism removal by Hazen[1] and more recently at Colorado State University[2] showed that shallow filter beds are less effective than deeper beds. According to Huisman and Wood[11] a typical bed depth for a new slow sand filter would be 1.2 to 1.4 m, and clean sand should be added to a slow sand filter when repeated scrapings have reduced the sand bed depth to 0.5 - 0.8 m.

The removal of microorganisms by slow sand filtration is less effective when the sand is clean (as in a new filter), when water temperature is close

to 0°C, when filtration rates are in the higher portion of the usual design rates, and when scraping to remove sand has decreased the depth of the filter bed. Of the factors that tend to degrade filter performance, water temperature can not be controlled by the design engineer. In the northern United States, and in mountain communities where raw water is very cold for long periods of time, conservative filter design should be used to compensate for the reduction of efficiency that is caused by the cold temperature.

2. Rapid Rate Filters

Rapid filtration processes and processes used to condition water for filtration (coagulation, flocculation and sedimentation) can bring about reductions in the numbers of microorganisms in water. Several investigations on the microorganism removal capability of clarification processes are presented in this part of the chapter.

Studies on removal of viruses by coagulation and sedimentation were reviewed by Sproul,[12] who concluded that removal of enteric viruses from water would range from 90 to over 99.99 percent. This conclusion was based on studies of poliovirus and Coxsackie A2 in which metallic coagulants (ferric or aluminum salts) were used. Sproul also reported that maximum virus removal occurred at or near the metallic coagulant dose resulting in maximum turbidity removal.

Engelbrecht et al.[13] reported that when ferric chloride or aluminum sulfate was used for coagulation, and when turbidity removal was optimum, typical removals for total coliforms by coagulation-sedimentation ranged from 90 to 99 percent.

Cyst removal by coagulation and sedimentation has also been evaluated. The U.S. Army tested its Mobile Water Purification Unit, Model 1940, and found that sedimentation removed 98.5 percent and 99.8 percent of applied E. histolytica cysts in two tests in which alum and soda ash were used for

coagulation.[14] Arozarena performed jar tests for removal of G. muris cysts from a low turbidity (1 - 2 NTU) gravel pit water[15] and found that cyst removal by alum coagulation was about 90 percent or higher in the pH range of 6 to 9, with maximum removals exceeding 99 percent. (Table 5). Cyst removal by alum coagulation could be improved by use of cationic polymer to supplement alum and by use of nonionic polymer to strengthen floc. Arozarena found that cyst removal by sedimentation usually was similar to turbidity removal, when aluminum sulfate was used as the coagulant.

Microorganism removal by coagulation and rapid filtration has been evaluated by numerous investigators.(3, 4, 7, 9, 14, 16, 17, 18) Water filtration studies have repeatedly shown that effective coagulation is needed to attain high percentages of removal of microorganisms by rapid filtration on a consistent basis. Microorganisms, like other small particles, must be destabilized to be removed efficiently in the rapid filtration process. This has been demonstrated when conventional treatment processes, including sedimentation, have been used, and when direct filtration without sedimentation has been employed. (Table 6). Rapid rate filtration of uncoagulated water can not be depended upon to give consistently high removals by microorganisms. Good coagulation was considered to have been attained when filtered water turbidity was well below 1.0 NTU. Inadequate coagulation is that which resulted in filtered water turbidity close to or greater than 1.0 NTU. In some cases, comments on the quality of coagulation were provided by the researchers[3, 14, 18].

A number of aspects of filter operation can adversely affect microorganism removal by rapid rate filtration. Among these are interruption of chemical feed, poor filter efficiency at the beginning of a run (before

ripening has occurred), sudden increases in filtration rate, and turbidity breakthrough that occurs with higher headloss at the end of a run.

Interruption of coagulant feed can cause rapid degradation of water quality. This was shown by Hazen's experiments[3] with the Warren Filter at Pittsburgh in 1898 (pp. 170, 171). Raw water and coagulant were introduced at one end of the elliptical settling basin, which had a flow-through time of forty minutes when the filter operated at 2 gpm/sf (4.9m/hr). During a run conducted on May 1, the run was begun at 8:36 a.m. and coagulant feed was shut off at 9:02 a.m. The bacteria count was 28 per mL at 9:30 a.m., and it rose to over 1000 per mL at 11:00 a.m., remaining at that level for the next 12 hours. Several days later, when coagulation was resumed, and the filter was backwashed, the bacteria count dropped from over 1000 per mL to under 10 per mL in three hours. Arozarena[15] demonstrated that interruption of coagulant feed caused an increased concentration of G. muris cysts in filtered water. In a run with an alum dose of 22 mg/L, cyst concentration rose from less than 80 cysts/L with coagulation to 790 and then 1760 cysts/L after the chemical feed was shut off. The large increase in cysts occurred even though filtered water turbidity rose from 0.27 NTU with coagulation to only 0.37 NTU and later 0.57 NTU without coagulation. In a second experiment of this nature, water was coagulated with 5 mg/L alum and 0.9 mg/L cationic polymer. Filtered water turbidity was 0.28 NTU, and cyst concentration was 70 per L. After chemical feed was shut off, turbidity rose to 0.38 NTU, but the cyst concentration rose to 3310 cysts/L.

Filtered water quality can be poor at the beginning of a run, after backwashing but before a filter has ripened. In experiments with the Warren Filter at Pittsburgh, Hazen[3] showed that bacteria counts in filtered water were as much as 5 to 10 times higher during the first 20 minutes

after backwashing, as compared to counts at the end of the prior run or 50 to 60 minutes after the new run had begun (pp. 167, 168). Logsdon et al.[16] reported that G. muris cyst concentrations observed during the ripening phases (the first half hour) of three filter runs were from 10 to 25 times higher than cyst concentrations measured later in the runs. but in three other runs, this phenomenon was not observed. These results suggest that the practice of filtering to waste for perhaps 10 to 30 minutes immediately after backwash may have merit.

The detrimental effect of rate changes on filtered water quality has been shown by Cleasby et al.[19] and by Di Bernardo and Cleasby.[20] This effect was demonstrated for filters removing iron and for filters operated for turbidity removal. Similar results were observed in a filter operated for Giardia cyst removal.[16]

Turbidity breakthrough at the end of a filter run can also result in large numbers of microorganisms passing into filtered water. Robeck[7] showed that a turbidity increase at the end of a filter run was associated with an increase in the poliovirus concentration in filtered water. Logsdon et al.[16] showed that turbidity breakthrough was associated with passage of large numbers of G. muris cysts. The increase in cyst concentration was not in direct proportion to the increase in turbidity, but was in fact much greater than the turbidity increase. In one run in which cysts were added to the raw water during the first 31 hours of operation, a turbidity increase from 0.4 to 0.7 NTU resulted in an increase in Giardia cyst concentration from 740 to 2900 cysts/L. The latter concentration was observed two hours after the supply of cysts had been exhausted. Turbidity breakthrough can cause previously stored contaminants to be dislodged from the filter bed and

discharged into the filtered water. Under such circumstances, effluent concentration from a filter can exceed the influent concentration for the contaminant.

These rapid rate filtration results show the need for careful control of coagulation chemistry and for continuous or frequent monitoring of the effluent turbidity at each filter in a treatment plant. Rapid rate filters are most effective for removal of microorganisms when coagulation pH is controlled at the optimum range, when the dose of coagulant is adequate, when floc is strong enough to resist breakthrough, when abrupt filtration rate increases are avoided, when filtered water turbidity is maintained well below 1.0 NTU, and when filtered water turbidity increases are not allowed to occur during a filter run.

3. Diatomaceous Earth Filters

Diatomaceous earth filtration can remove a variety of microorganisms. Performance is related to size of microorganism, grade of DE used, thickness of precoat, and presence or absence of special coatings on the diatomaceous earth.

Two investigations of virus removal have been conducted[21,22] with T-2 bacteriophage and poliovirus Mahoney Type I inoculated in the water. Malina et al.[21] showed that bacteriophage removal was lower when a more porous grade of DE was used and higher when a finer grade of DE was used. The best removal was achieved when diatomaceous earth was coated with hydrous iron oxides or when cationic polymer was added to the raw water. One 12-hour run was conducted in which cationic polymer (0.07 mg/L) was added to raw water. The feed water contained 1,700 pfu/L (plaque forming units/liter). No bacteriophage were detected in the filtered water in 11 samples, but in one of the 12 samples, two plaque-forming units (PFU) were found. The feed water contained 1,700 pfu/L. This filtration technique thus attained a

reduction of T-2 virus of 99.88% or better in these experiments.

In research with poliovirus, Malina et al.[22] in the first phase of their research showed that the use of coated DE filter aid or the use of cationic polymer in the raw water enhanced virus removal as compared to uncoated diatomite, so two 12-hour runs were performed to evaluate these techniques for poliovirus removal. In one run, Hyflo® filter aid was coated with 1 mg of cationic polymer per gram of filter aid, and virus was added to the feed water. No viruses were recovered in 11 of the 12 filtered water samples, indicating a virus removal exceeding 99.95%. A 99% removal of virus was attained in the single sample that did contain virus. In a 12-hour run in which uncoated diatomaceous earth was used and 0.14 mg/L of cationic polymer was added to the raw water as a supplemental treatment, no viruses were recovered from any of the twelve filtered water samples. The recovery of only one virus plaque forming unit would have yielded 99.96% removal rate, so the performance exceeded this percentage.

Hunter et al.[23] studied coliform removal by DE filtration and concluded that penetration of the filter by coliforms was greater when the filter cake was more permeable. The most permeable grade tested (Hyflo)® had the lowest coliform removal (about 90% when raw water coliform count exceeded 1,000 per 100 mL). Removal for Celite 512® exceeded 99.0%. The finest grade of DE tested, Standard Super-Cel®, gave coliform removals of 99.86% or better when raw water coliform count was 19,000 per 100 mL. When Standard Super-Cel® was used, no coliforms were detected when raw water coliforms were in the range of 6 to 7,000 per 100 mL.

When coliforms did pass through the filter, the level of coliforms in filtered water was higher when influent coliform count was higher. In

actual practice, however, diatomaceous earth filtration would not be relied upon as the sole barrier to passage of bacteria in drinking water. For better control of coliforms, the benefit of using more permeable filter aid resulting in longer runs should be weighed against using less permeable filter aid, thus getting shorter runs but better coliform removal.

Research performed at Colorado State University[24] with the diatomaceous earth test filter has confirmed the earlier observation of Hunter et al. that fewer total coliforms pass through the DE filter as finer grades of diatomite are used and has shown that removals of standard plate count oganisms, total coliforms, and turbidity all improve as finer grades of DE are used. (Table 7). Because of the size differences of bacteria vs. the fine clays in the source water, the removal of turbidity-causing particles was less than the removal of microorganisms for most grades of DE. The finest grade tested, Filter Cel®, was very effective for turbidity removal, but this grade usually is not used in potable water treatment because of the high head loss caused by small particle size.

A comparison of turbidity removal by diatomaceous earth filtration and membrane filtration was made to learn what sizes of particles were causing the turbidity in the water used in the CSU research. A 5 um filter permitted passage of about 98% of the turbidity, more than the 88% passed by Celite 503®. A 1.2 um filter passed 64%, similar to the 72% passed by Celite 512®. The 9% passed by a 0.2 um membrane filter was similar to the 2% passed by FilterCel®. These results indicate that the particle sizes smaller than 1 um were causing a substantial amount of the turbidity in this water.

Research with alum-coated DE showed that diatomite onto which aluminum

hydroxide had been precipitated was more effective for removal of standard plate count organisms, total coliforms, and turbidity than the usual DE filtration technique in which the diatomaceous earth used for precoat and body feed is used as provided (uncoated) by the manufacturer. The use of alum coating resulted in a dramatic improvement in filtered water quality. (Table 8).

Research on diatomaceous earth filration during World War II led the U.S. Army to state (p. 27), "A filtration unit properly designed and operated would be expected to remove completely the cysts of Endamoeba histolytica."[14] The success of the U. S. Army in using DE filtration for E. histolytica cyst removal led to later research on D.E. filtration for removal of Giardia cysts.

Research on DE filtration, conducted with a 1 sq ft. filter, for removal of 9 um radioactive beads (Giardia cyst models), G. muris cysts, and G. lamblia cysts has shown that DE filtration is an effective treatment method for cyst-contaminated waters. Data obtained with radioactive beads indicated that a precoat thickness of 1.0 Kg/m^2 (0.2 lb/ft^2) should be used.[16] EPA research showed that a DE filter with adequate precoat and a clean septum could consistently remove more than 99% of the G. muris cysts applied to the filter.[16] Research with G. lamblia cysts at the University of Washington, also with the 1 sq. ft. filter, confirmed these results. Cyst removals for four filter runs ranged from 99.02% to above 99.87% in 12 separate determinations.[17] Similar results were obtained at McIndoe Falls, Vermont, with a 10 sq. ft. filter. In a test in which 8×10^6 G. lamblia cysts were spiked in the raw water, removal was 99.97 percent.[9]

The most thorough study of Giardia cyst removal conducted to date is the work done at Colorado State University.[9, 24] Filtration rates of 1 to 4 gpm/sf (2.4 to 9.8 m/hr) were evaluated, and a variety of DE grades was studied, using the 1 sq. ft. filter. (Table 9).

Of the 26 runs, the only one in which cysts were detected had a very high influent cyst concentration, 34,000 cysts per liter. When influent cyst concentrations ranged from 100 to 10,000 cysts/L, no cysts were detected in the filtered water. Results indicate that DE filtration is effective for cyst removal at rates of 2.4 to 9.8 m/hr. These experiments were performed with a raw water source having very fine turbidity-causing particles. With this water source, cyst removal efficiency was not related to turbidity removal by DE filters.

Field tests for removal of Giardia cysts were performed at the Cache la Poudre River and at Dillon, Colorado, at filtration rates of 2.4 to 9.8 m/hr. Celite 545® was used in the six filter runs in which cyst removal was studied. In five of the six runs, no cysts were detected, and removals exceeded 99.93% to 99.99%, depending on influent cyst concentration and the volume of filtered water sampled for cysts. Filtered water turbidity in these runs ranged from 0.3 NTU to 1.5 NTU.

During one of the six filter runs, cysts passed through the filter. When the filter was then subjected to leak testing, existence of a leak was confirmed. The turbidity of the filtered water in the run in which the leak occurred was 7.3 NTU, and cyst removal was 99.4%. These results suggest that when DE filtration equipment is properly maintained, this process is capable of removing over 99.9% of Giardia cysts from raw water, and that process efficiency is related to proper operation and maintenance of equipment rather than to effluent turbidity.

Studies cited above indicate that as particle size decreases from cysts to bacteria to virus, the straining mechanism for particle removal by DE filtration becomes less effective. Research has shown, however, that the use of cationic polymer or aluminum or iron salts to form a coating on

the DE can substantially enhance the removal of very small particles by DE filtration so that this process can also become a barrier to the passage of bacteria and viruses. Use of diatomaceous earth has been shown repeatedly to be effective for removal of cysts.

III. DISINFECTION

Disinfection is usually the final step in drinking water treatment and the primary means to prevent waterborne outbreaks. In some instances, disinfection is the only treatment provided. Although disinfection may be conducted continuously throughout the treatment process to prevent growth of nuisance microorganisms, the major goal of the process is to ensure inactivation of waterborne pathogens. Disinfection is not intended to sterilize water, i.e., to kill all living organisms in the water.

Selection of the disinfection process to be used in drinking water treatment depends on a number of factors[25] including:

1. efficacy against waterborne pathogens (bacteria, viruses, protozoans, etc.).
2. accuracy with which process can be monitored and controlled.
3. ability to maintain effective residual to counteract possible contamination after treatment.
4. effects on aesthetic quality.
5. availability of the technology for application on scale needed including cost considerations.

The disinfecting capabilities of a wide variety of chemical and physical agents have been investigated, but relatively few meet the above criteria and can be realistically considered for current use in drinking water disinfection. Given the heavy reliance on disinfection in preventing waterborne disease transmission those responsible for water treatment are

understandably reluctant to use innovative disinfection techniques in the absence of overwhelming favorable evidence. The increasing concern about the possibility of adverse health effects of disinfectants and their by-products has caused a reassessment of alternative disinfectants that may not produce chlorinated by-products, but might produce other by-products. In some cases, such as with chloramine, the alternative to free chlorine may not be as effective as chlorine, which has been studied extensively and has a long history of use in the United States.

The suitability of a large number of possible drinking water disinfection methods was evaluated recently by the Safe Drinking Water Committee of the National Research Council[26]. (Table 10). Although several of the agents provided adequate inactivation, the Committee regarded only free chlorine, ozone and chlorine dioxide as suitable for actual use in drinking water disinfection. Other disinfectants were not recommended for a variety of reasons, including poor biocidal activity, lack of technological experience, and adverse health effects to some population groups. For many utilities conversion of systems from free chlorine to chloramines is the simplest and most economical method for reducing formation of trihalomethanes in finished drinking water, and these utilities have increased their reliance on chloramines in spite of the poor biocidal capability of chloramines.

The most important single factor considered in choosing a particular disinfectant is its effectiveness against various types of pathogenic micro-organisms. A large body of literature on the biocidal characteristics of drinking water disinfectants has been established. The information is based primarily on laboratory studies, conducted under closely controlled conditions. For comparison of biocidal efficiency Baumann and Ludwig[27]

suggested the use of an equation based on log-log plots of time vs. disinfectant concentration needed to inactivate a certain percentage (e.g. 99%) of a given microorganism under defined pH and temperature conditions. The general equation is

$$C \cdot t' = K$$

in which C is the disinfectant concentration, t' is the contact time and K is the constant for a particular microorganism. The concept was to provide a method for determining contact time and disinfectant concentration needed to inactivate a particular pathogen of concern under defined conditions, and this formula has been used for the disinfection data in this chapter.

In actual water treatment practice the disinfectant concentration is generally known to a greater degree of accuracy than the contact time. Often contact time is estimated on the basis of theoretical flow through or displacement time (water volume divided by flow rate). Few chlorine contact basins have conditions of plug flow, however, so the actual retention time for a portion of the water flowing through the contact basin is only a fraction of the theoretical time, because of short circuiting. Additional information on this is presented in Chapter 9.

A. General Considerations

Disinfectant effectiveness is influenced by several physical and chemical factors. One of the most important of these is water temperature. For all chemical disinfectants, inactivation rates decrease as water temperatures decrease. Because of this effect cold water temperature represents a "worst case" condition for disinfection effectiveness. Most of the information presented below is based on experiments conducted at 5°C or less. Water pH also can affect inactivation rates. In the case of free

chlorine, water pH determines the proportions of the active agents, hypochlorous acid (HOCl) and hypochlorite ion (OCl^-) present. Since the HOCl species is a much more effective disinfectant, lower pH's (pH 6 - 7.5) which result in formation of HOCl are favorable for rapid inactivation while higher pH's (pH 8 - 10) at which OCl^- predominates result in slower rates of inactivation. With chlorine dioxide (ClO_2) which does not dissociate into different chemical species, inactivation is more rapid at higher pH's (pH 9) than at lower pH's (pH 7).[28, 29] The disinfection capability of ozone appears to be unaffected by pH.[30]

B. Microorganism Inactivation Capabilities

1. Chlorine Species

Results of a number of studies of the disinfection efficiency of free chlorine species for inactivation of representative enteric bacteria, enteroviruses and protozoan pathogens are shown in Table 12. The polioviruses are much more resistant than *E. coli* to both species of free chlorine, and cysts of *G. lamblia* and *E. histolytica* are in turn nearly 100 fold more resistant than poliovirus. The much greater bactericidal and virucidal efficiency of HOCl as compared with OCl^- also is evident.

Results of similar studies using inorganic chloramine disinfectants are shown in Table 13. In general, for all types of microorganisms, C.t' values for chloramines are higher than C.t' values for free chlorine species. C.t' values for the enteroviruses are extremely high while values for *G. lamblia* cysts are lower, in contrast to the findings for free chlorine species. Although *E. histolytica* cyst inactivation data suitable for C·t' comparison are not available, studies that have been done[38] indicate that *E. histolytica* cyst resistance to inorganic chloramines

is similar to that of G. lamblia cysts. Again, increased inactivation rates at higher temperatures are seen.

2. Chlorine Dioxide

C·t' data for ClO_2 are shown in Table 14. The data indicate that at pH 7.0, ClO_2 is a somewhat weaker bactericide and virucide than HOCl. In contrast to free chlorine, the efficiency of ClO_2 increases as pH increases, as the poliovirus results indicate that ClO_2 is a more efficient virucide than HOCl. Protozoan cyst data suitable for C·t' comparisons are not available.

3. Ozone

C·t' values for ozone are shown in Table 15. G. muris cysts are on the order of 10 fold more resistant than poliovirus 1 which in turn is about 10 fold more resistant than E. coli. Overall comparison of the ozone C·t' values with those of ClO_2 and chlorine species show that ozone is a much more potent biocide than the other disinfectants.

C. Relevance to Disinfection Practice

The laboratory studies clearly indicate that there are differences in relative disinfectant efficiency related to the chemical nature of the disinfectant, and the type of microorganism as well as physical factors such as pH and temperature. In general, enteric bacteria are the most sensitive to all disinfectants discussed, with the enteroviruses intermediate in resistance followed by protozoan cysts. An anomaly may exist in the case of inorganic chloramine in that Giardia cysts appear to be more sensitive to this disinfectant than enteroviruses. The reason for this is not presently understood. Although less quantifiable, there are similar indications from studies of inactivation of E. histolytica cysts. When the disinfectants

considered are compared on a weight basis, ozone causes the most rapid inactivation of all types of microorganisms. Chlorine dioxide and free chlorine in the form of HOCl are about equivalent. Chlorine dioxide has an advantage over free chlorine in that it is less likely to be depleted through reactions with ammonia. Both free chlorine in the form of OCl^- and chloramines are much weaker biocides than chlorine dioxide.

The potential for interference with disinfection efficiency by protection of microorganisms associated with various types of particles has been demonstrated for chlorine[42, 43] chlorine dioxide[44] and ozone.[45, 46] Association with organic particles such as wastewater effluent solids and cell debris offers a much higher degree of protection than association with inorganic particles such as clays and alum floc, and none of the disinfectants appears to possess any particular ability to penetrate such particles. The results of these studies illustrates the need for physical removal of particles in preparing water for the disinfection step in order to ensure protection against waterborne disease transmission.

IV. SUMMARY

Water clarification processes that are properly designed and operated can be an effective barrier to the passage of microorganisms into finished drinking water. At conventional treatment plants that employ coagulation, flocculation, sedimentation and filtration, the sedimentation process constitutes one barrier to passage of pathogens, and a second is provided by filtration. At rapid rate direct filtration plants, slow sand filtration plants, and diatomaceous earth filtration plants, sedimentation would not be used, so the only physical removal step (barrier) is the filtration process. When these latter processes are considered, engineers should be

careful to verify that the raw water quality is appropriate for filtration without prior sedimentation.

Water filtration plants must be operated and maintained properly in order to achieve their potential for microorganism removal. At plants without sedimentation, extra care must be taken to assure that the filtration process is an effective barrier. This chapter discusses facets of plant operation that need attention.

Disinfection is a major barrier to the passage of pathogens into finished drinking water, and the one upon which the most reliance has been placed in this century. Although numerous chemical and physical agents might inactivate microorganisms, in actual practice only chlorine, chlorine dioxide, and ozone find wide acceptance for drinking water treatment. The vast majority of water utilities in the United States use chlorination, either free chlorine or chloramine, or both, for disinfection.

Engineers and treatment plant operators need to be aware that disinfection efficacy can be influenced by the type and concentration of disinfectant used, contact time, water temperature, water turbidity, type of microorganism, and in some instances, pH. Some pathogens are more difficult to inactivate than are indicator organisms, so caution must be used when assessing efficacy of disinfection in terms of inactivation of indicator organisms. In spite of these caveats, disinfection remains the most effective and most relied upon barrier in water treatment. For many ground waters, disinfection constitutes the only treatment barrier, with major reliance being placed on source protection barriers. In these situations, consistent attainment of effective disinfection is particularly important.

V. REFERENCES

1. Hazen, A., The Filtration of Public Water Supplies, Third Edition, John Wiley & Sons, New York, 1913, p. 32.

2. Brink, D. R., et al. Removal of Giardia lamblia from Water Supplies; Appropriate Treatment Technologies for Small Systems, Environmental Engineering Technical Report 5847-83-3. Colorado State University, Fort Collins, Colorado, pp. 1-14.

3. Report of the Filtration Commission of the City of Pittsburgh, Pennsylvania, January, 1899, pp. 124, 125, 138, 139, 152-154.

4. Cleasby, J. L., Slow Sand Filtration and Direct In-Line Filtration of a Surface Water, in Proc. AWWA Seminar, Innovative Filtration Techniques, Am. Water Works Assoc. Publ. No. 20176, 10, 1983.

5. Bellamy, W. D., et al. Slow Sand Filtration of Giardia Cysts and Other Substances, submitted to Jour. Am. Water Works Assoc.

6. Windle Taylor, E. Forty-fourth Report on the Results of the Bacteriological, Chemical, and Biological Examination of the London Waters for the Years 1969-1970, Metropolitan Water Board, London, p. 52.

7. Robeck, G. G., Clarke, N. A., and Dostal, K. A., Effectiveness of Water Treatment Processes in Virus Removal, Jour. Am. Water Works Assoc., 54, 1275, 1962.

8. Jordan, H. E., Fifteen Years Filtration Practice in Indianapolis, in Proc. of the Thirteenth Annual Convention of the Indiana Sanitary and Water Supply Assoc., 1920.

9. Logsdon, G. S., Hendricks, D. W., Pyper, G. R., Hibler, C. P., and Sjogren, R., Control of Giardia Cysts by Filtration: The Laboratory's Role, in Proc. of the 11th Annual AWWA Water Quality Technology Conf., 265, 1984.

10. Poynter, S. F. B., and Slade, J. S., The Removal of Viruses by Slow Sand Filtratlion, Prog. Water Tech., 9, 75, 1977,

11. Huisman, L. and Wood, W. E., Slow Sand Filtration, World Health Organization, Geneva, 1974, Chapter 4.

12. Sproul, O. J., Critical Review of Virus Removal by Coagulation Processes and pH Modifications, EPA-600/2-80-004, U.S. Environmental Protection Agency, Cincinnati, p. 2.

13. Engelbrecht, R. S., et al., Acid-Fast Bacteria and Yeasts as Indicators of Disinfection Efficiency, EPA-600/12-79-091, U.S. Environmental Protection Agency, Cincinnati, p. 7.

14. Efficiency of Standard Army Water Purification Equipment and of Diatomite Filters in Removing Cysts of Endamoeba histolytica from Water, War Department Report 834, 3 July, 1944, pp. 63-82.

15. Arozarena, M. M., Removal of Giardia muris Cysts by Granular Media Filtration, unpublished Master of Science Thesis, University of Cincinnati, 1979, pp. 34-45.

16. Logsdon, G. S., et al., Alternative Filtration Methods for Removal of Giardia Cysts and Cyst Models, Jour. Am. Water Works Assoc., 73, 111, 1981.

17. DeWalle, F. B., Engeset, J., and Lawrence, W., Removal of Giardia lamblia Cysts by Drinking Water Treatment Plants, EPA-600/2-84-069, U.S. Environmental Protection Agency, Cincinnati, 1984.

18. Baylis, J. R., Gullans, O., and Spector, B.K., The Efficiency of Rapid Sand Filters in Removing the Cysts of Amoebic Dysentery Organisms from Water, Public Health Reports, 51, 1567, Nov. 13, 1936.

19. Cleasby, J. L., Williamson, M. M., and Baumann, E. R., Effect of Filtration Rate Changes on Quality, Jour. Am. Water Works Assoc., 55, 869, 1963.

20. DiBernardo, L., and Cleasby, J. L., Hydraulic Considerations in Declining-Rate Filtration, Jour. of Env. Engr. Div., Am. Soc. of Civil Engrs., 106, 1023, 1980.

21. Malina, J. F., Jr., Brown, T. S., and Moore, B. D., T-2 Bacteriophage Removal by Diatomaceous Earth Filtration, Universtiy of Texas, Austin, 1971.

22. Malina, J. F., Jr., Moore, B. D., and Marshall, J. L., Poliovirus Removal by Diatomaceous Earth Filtration, University of Texas, Austin, 1972.

23. Hunter, J. V., Bell, G. R., and Henderson, C. N., Coliform Organism Removals by Diatomite Filtration, Jour. Am. Water Works Assoc., 58, 1160, 1966.

24. Lange, K. P., Bellamy, W. D., and Hendricks, D. W., Filtration of Giardia Cysts and Other Substances, Volume I: Diatomaceous Earth Filtration, EPA-600/2-84-xxx, U.S. Environmental Protection Agency, Cincinnati, 1984.

25. Symons, J.M., J.K. Carswell, R.M. Clark, P. Dorsey, E.E. Geldreich, W.P. Heffernan, J.C. Hoff, O.T. Love, L.J. McCabe, and A.A. Stevens. 1980. Ozone, Chlorine Dioxide, and Chloramines as Alternatives to Chlorine for Disinfection of Drinking Water: State of the Art. pp 2-86, In J. Katz, ed. Ozone and Chlorine Dioxide Technology for Disinfection of Drinking Water. Noyes Data Corp., Park Ridge, N.J.

26. National Research Council, Safe Drinking Water Committee, The Disinfection of Drinking Water. Drinking Water and Health. Vol. 2 pp. 5-137. National Academy Press, Washington, D.C., 1980.

27. Baumann, E.R. and Ludwig, D.D., Free Available Chlorine Residuals for Small Nonpublic Water Supplies, J. Am. Water Works Assoc., 54, 1379, 1962.

28. Benarde, M.A., Israel, B.M., Olivieri, U.P., and Granstrom, M.L. Efficiency of Chlorine Dioxide as a Bactericide. Appl. Microbiol. 13, 776, 1965.

29. Cronier, S.D. Destruction by Chlorine Dioxide of Viruses and Bacteria in Water. M.SC thesis, University of Cincinnati, 85 pp., 1977.

30. Morris, J.C. The Role of Ozone in Water Treatment. Proc. 96th Ann. Conf. Am. Waterworks Assn., New Orleans, LA. Paper 26-29, Vol. 2, 1976.

31. Scarpino, P.V., Lucas, M., Dahling, D.R., Berg, G., and Chang, S.L. Effectiveness of Hyprochlorous Acid and hyprchlorinte ion in Distruction of Viruses and Bacteria in Chemistry of Water Supply Treatment and Distribution A.J. Rubin, Ed. Ann Arbor Sci. Publ., Ann Arbor, MI pp 359-368, 1974.

32. Engelbrecht, R.S., Weber, M.J., Salter, B.L., and Schmidt, C.A. Cooperative Inactivation of Viruses by Chlorine. Appl. Env. Microbiol. 40, 249, 1980.

33. Snow, W. B. Recommended Residuals for Military Water Supplies. J. Am. Water Works Assn. 48, 1510, 1956.

34. Jarroll, E.L., Bingham, A.K., and Meyer, E.A. Effect of Chlorine on Giardia lamblia Viability. Appl. Env. Microbiol. 41, 483, 1981.

35. Siders, D.L., Scarpino, P.V., Lucas, M., Berg, G., and Chang, S.L. Destruction of Viruses and Bacteria in Water by Monochloramine. Absta. No. E27. Abstr. Ann. Mtg. American Society for Microbiology, Washington, D.C. 1973.

36. Esposito, P., Scarpino, P.V., Chang, S.L., and Berg, G. Destruction by Dichloramine of Viruses and Bacteria in Water. Abstr. No. G99. Abstr. Ann. Mtg. American Society for Microbiology, Washington, D.C. 1974.

37. Bingham, A. K. and Meyer, E. A. Unpublished data, 1984.

38. Stringer, R. and Kruse, C.W. Amoebic Cysticidal Properties of Halogens in Water. Proc. National Specialty Conference on Disinfection, Amherst, Mass, July 1970, pp 319-338.

39. Katznelson, E., Kletter, B., and Shuval, H.I. Inactivation Kinetics of Viruses and Bacteria in Water by Use of Ozone. J. Am. Water Works Assn. 66, 725, 1974.

40. Roy, D., Engelbrecht, R.S., and Chian, E.S.K. Comparative Inactivation of Six Enteroviruses by Ozone. J. Am. Water Works Assn. 74, 660, 1982.

41. Wickramanayake, G.B., Rubin, A.J., and Sproul, O.J. Inactivation of Naegleria and Giardia Cysts in Water by Ozonation. J. Water Pollution Control Fed. In Press, 1984.

42. Hoff, J. C. The Relationship of Turbidity to Disinfectant of Potable Water in Evaluation of the Microbiology Standards for Drinking Water. C. H. Hendricks, Ed. EPA-570/9-78-00C, pp 103 - 117, 1978.

43. Hoff, J.C. and Geldreich, E.E. Comparison of the Biocidal Efficiency of Alternative Disinfectants. J. Am. Water Works Assoc. 73, 40, 1981.

44. Brizano, F. A. O., Scarpino, P.V. Cronier, S., and Zink, M.L. Effect of Particulates on Inactivation of Enteroviruses by Chlorine Dioxide in Progress in Wastewater Disinfection Technology, A. D. Venosa, Ed. EPA-600/9-79-018, pp 86-94, 1979.

45. Walsh, D.S., Buck, C. E., and Sproul, O.J. Ozone Inactivation of Floc Associated Viruses and Bacteria. J. Env. Eng. Div. ASCE 106, 711, 1980.

46. Foster, D.M., Emerson, M.A., Buck, C.E., Walsh, D. S., and Sproul, O.J. Ozone Inactivation of Cell- and Fecal-Associated Viruses and Bacteria. J. Water Polln. Control Fed. 52, 2174, 1980.

Table 1.

Effect of Media Size on Removal of Microorganisms by Slow Sand Filtration

Effective Size mm	Reported Removal Percentages		
	S. Marcesiens		Total coliform
	Hazen, 1892	Hazen, 1893	Hendricks, 1983
0.09	99.98	99.98	--
0.14	99.96	99.97	--
0.30	99.87	99.99	--
0.26	--	99.90	--
0.29	--	99.84	--
0.3	--	--	87
0.38	--	99.84	--
0.5	--	--	83

Table 2.

Effect of Filter Bed Condition on Microorganism Removal by Slow Sand Filtration

Ref.	Location	Organism	Condition of Filter Bed	Removal Percentage or Concentration in Effluent
3	Pittsburgh	plate count bacteria	First two days after scraping	139 to 459 per mL
3	Pittsburgh	plate count bacteria	Established biological population after first two days since scraping	59 to 112 per mL
4	Iowa State U.	total coliform	First two days after scraping	83.0% to 99.8%
4	Iowa State U.	total coliform	Remainder of runs, excluding first two days after scraping	96.7% to 100%
7	USPHS	polio virus type I	clean sand	22% to 96%
6	London	polio virus type I	sterilized sand	little or no removal
6	London	polio virus type I	established biological population	99.9% or more
5	Colorado St. Univ. (CSU)	total coliform	new filter sand	93%
5	CSU	total coliform	filter bed scraped & disturbed	95.3%
5	CSU	total coliform	established schmutzdecke	99.89%
5	CSU	*Giardia* cysts	new filter sand	99.0% or more
5	CSU	*Giardia* cysts	bed scraped	98.7% or more
5	CSU	*Giardia* cysts	established schmutzdecke	99.7% or more

Table 3.

Effect of Temperature or Season on Microorganism Removal by Slow Sand Filtration

Reference	Location	Organism	Temperature or Season	Removal Percentage
3	Pittsburgh	plate count bacteria	Feb. to Nov.	generally 99% or higher
3	Pittsburgh	plate count bacteria	Dec. and Jan.	97.2% to 98.9%
8	Indianapolis	B. coli	March to Nov.	99.2% to 99.9%
8	Indianapolis	B. coli	Dec. to Feb.	94.1% to 97.2%
9	Vermont	plate count bacteria	June to Sept.	98.8%
9	Vermont	plate count bacteria	Oct. to Jan.	98.1%
9	Vermont	total coliform	June to Sept.	99.4%
9	Vermont	total coliform	Oct. to Jan.	97.9%
2	CSU	total coliform	15°C	97%
2	CSU	total coliform	5°C	87%
10	London	poliovirus I	16°C to 18°C	up to 99.997%
10	London	poliovirus I	5°c to 8°C	99.68%
9	Vermont	Giardia lamblia cyst	21°C	99.99%
9	Vermont	Giardia lamblia cyst	0.5°C	93.7%
5	CSU	Giardia cyst	15°C	99.9% or higher
5	CSU	Giardia cyst	5°C to 15°C	99.9% or higher

Table 4.

Effect of Filtration Rate on Microorganism Removal by Slow Sand Filtration

Reference	Organism	Filtration Rate, m/hr 0.02	0.04	0.08	0.12	0.20	0.40
		Removal Percentage Observed					
1	*B. prodigiosus*, or *S. marsescens*	99.98	99.86	99.89	99.69	----	----
5	total coliform	----	99.96	----	99.67	----	98.98
5	fecal coliform	----	99.84	----	98.45	----	98.65
5	plate count	----	91.40	----	89.47	----	87.99
5	*Giardia* cyst	----	99.991	----	99.994	----	99.98
10	Polio virus type I	----	----	----	----	99.78	99.93
10	Polio virus type I	----	----	----	----	99.865	99.997

Table 5.

Summary of Jar Test *Giardia muris* Cyst Removal Efficiencies with Alum Coagulation (15)

a. 25 mg/L Alum, Raw Water 2.3 NTU

pH	Giardia Cyst % Removal	Settled Turbidity NTU
5.9	58.4	1.5
6.6	>89.6	0.20
7.5	>88.8	0.20
7.9	>89.9	0.28
8.6	>90.5	0.35

b. pH 6.4 - 6.7, Raw Water 2.1 NTU

Alum mg/L	Giardia Cyst % Removal	Settled Turbidity NTU
5	95.7	3.7
10	>99.4	0.82
25	>99.4	0.29
50	>99.4	0.29

c. pH 7.2, 10 mg/L alum, Raw Water 1.4 NTU

Nonionic Polymer mg/L	Giardia Cyst % Removal	Settled Turbidity NTU
0	65.4	0.24
0.01	95.0	0.25
0.05	96.2	0.18
0.1	>96.2	0.17
0.5	>96.2	0.18
1.0	>92.3	0.19

d. pH 6.5 - 6.7, 5 mg/L Alum, Raw Water 1.6 NTU

Cationic Polymer mg/L	Giardia Cyst % Removal	Settled Turbidity NTU
0	96.0	0.40
0.1	98.8	0.48
0.2	99.1	0.52
0.4	99.3	0.58
0.8	>99.0	0.78
1.6	96.3	1.0

Table 6.

Effect of Pretreatment on Microorganism Removal by Rapid Filtration

Ref.	Processes Used					Organism	Percentage Removal Reported		
	Coagulation	Flocculation	Sedimentation	Sand Media	Dual or Mixed Media		Good Coagulation	Inadequate Coagulation	No Coagulation
3	X		X	X		bacteria	98.8%	--	35% to 86%
3	X		X	X		bacteria	98.5%	--	38% to 70%
9	X				X	coliform			1% to 99.9%
4	X				X	coliform	86% to 96.5%	--	
7	X				X	poliovirus I	90% to 99%	--	1% to 50%
7	X	X	X		X	poliovirus I	>99.7%	--	
16	X				X	Giardia muris	59% - 99.98%	23% - 94%	59% to 94%
17	X	X			X	Giardia lamblia	95% - 99.97%	64% - 92%	48%
9	X				X	Giardia cyst	83% of samples have removal $\geq$ 99.0%	--	Removal <80% for half of samples
14	X			X		E. histolytica cyst	99.6 - 99.9%	96%	80% to 88%
14	X	X	X	X		E. histolytica cyst	99.94 - 99.97%	--	98.3%
18	X	X		X		E. histolytica cyst	99.99%	--	--

Table 7

Average Removal Percentages of Total Coliform Bacteria, Standard Plate Count Bacteria, Turbidity and *Giardia* Cysts with Various Grades of Diatomaceous Earth, CSU

Grade of Diatomaceous Earth	Celite 545®	Celite 535®	Celite 503®	Hyflo Super-Cel®	Celite 512®	Standard Super-Cel®	Filter Cel®
Number of tests	15	2	10	4	2	3	2
Median Particle Size (um)	26.0	25.0	23.0	18.0	15.0	14.0	7.5
Total Coliform Removal (%)	49.46	85.45	69.41	92.60	97.95	99.90	99.86
Standard Plate Count Removal (%)	58.42	80.51	69.10	75.29	78.63	99.11	99.85
Turbidity Removal (%)	13.36	12.50	11.97	23.56	31.14	49.77	97.64
Giardia Cyst Removal (%)	>99.7	>99.5	>99.7	>99.4	--	--	--

From Logsdon et al.[9]

Table 8.

Removal percentages of total coliform bacteria, standard plate count bacteria, and turbidity for diatomaceous earth grades C-545 and C-503 coated at various alum concentrations. (24)

Grade	Alum Coat % by wt.	Average Removals		
		Total Coliform (%)	Standard Plate Count (%)	Turbidity (%)
C-545	2	-	-	66.11
	4	99.02	95.02	86.41
	5	99.86	98.56	98.38
C-503	5[a]	98.01	79.31	79.06
	5	99.56	93.25	94.41
	5[b]	96.33	99.57	98.61
	8	99.83	99.52	98.80

[a]Bodyfeed concentration was increased to 50 ppm after 3 hours of testing at 25 ppm

[b]Bodyfeed concentration 50 ppm, all other bodyfeed rates were 25 ppm

Table 9

Giardia Cyst and Turbidity Data for Diatomaceous Earth Filtration Tests[9]

Run No.	Celite® Grade	Filt. Rate (m/hr)	Temp. (°C)	Length of Test (min)	Influent *Giardia* Cyst Concentration: Added to Feed Water (cysts/L)	Influent *Giardia* Cyst Concentration: Detected in Feed Water (cysts/L)	No. of Cysts Detected in Effluent Sample (No.)	Effluent *Giardia* Concentration (cysts/L)	*Giardia* Cyst Percent Removal (%)	Turbidity: Influent NTU	Turbidity: Effluent NTU
13	545	2.44	5	90	100	27.7	0	<0.701	>99.299	3.5	3.3
18	545	2.44	13	90	100	50.5	0	<0.461	>99.539	4.2	3.6
20	545	2.44	5	90	500	229.0	0	<0.465	>99.907	4.4	3.5
28	545	2.44	5	340	770	75.0	0	<0.326	>99.958	4.6	3.8
42	545	2.44	13	145	10,000	-	0	<0.112	>99.998	9.1	6.9
43	545	2.44	15	150	5,460	-	0	<0.108	>99.998	-	-
45	545	2.44	14	260	8,850	-	0	<0.063	>99.999	-	-
41	545	2.44	12	55	3.36×10^4	-	1,700	25.148	99.925	-	-
49	545	2.44	10.5	980	2,467	-	0	<0.0004	>99.999	9.9	8.4
14	545	4.88	5	90	100	44.4	0	<0.425	>99.575	3.5	3.4
19	545	4.88	13	90	100	65.9	0	<0.323	>99.677	4.4	3.6
21	545	4.88	5	90	500	330.0	0	<0.326	>99.935	4.4	3.6
17	545	9.76	5	90	100	47.0	0	<0.443	>99.557	4.2	3.7
26	545	9.76	5	90	500	31.5	0	<3.342	>99.332	4.2	3.8
15	535	2.44	5	90	100	45.5	0	<0.423	>99.577	3.6	3.2
16	535	4.88	5	90	100	45.5	0	<0.453	>99.547	3.6	3.1
11	503	2.44	5	90	100	76.4	0	<0.257	>99.743	3.5	3.3
25	503	2.44	5	90	500	127.0	0	<0.691	>99.862	4.4	3.7
44	503	2.44	15	275	5,460	-	0	<0.058	>99.998	-	-
12	503	4.88	5	90	100	40.0	0	<0.481	>99.519	3.6	3.3
22	503	4.88	13	90	100	59.0	0	<0.357	>99.643	4.2	3.6
24	503	4.88	5	90	500	127.0	0	<0.895	>99.821	4.3	3.5
27	503	9.76	13	90	100	33.0	0	<0.532	>99.468	4.2	3.7
9	Hyflo	2.44	5	90	100	41.4	0	<0.478	>99.522	3.7	3.0
10	Hyflo	4.88	5	90	100	27.2	0	<0.694	>99.306	3.5	3.1
45	545	4.88	14	40	8,850	-	0	<0.408	>99.995	6.6	-

Table 10.

Status of Possible Methods for Drinking Water Disinfection[26]

Disinfection Agent	Suitability as Inactivating Agent	Limitations	Suitability for Drinking Water Disinfection[a]
Chlorine	Yes	Efficacy decreases with increasing pH; affected by ammonia or organic nitrogen	Yes
Ozone	Yes	On-site generation required; no residual; other disinfectant needed for residual	Yes
Chlorine dioxide	Yes	On-site generation required; interim MCL 1.0 mg/liter	Yes
Iodine	Yes	Biocidal activity sensitive to pH	No
Bromine	Yes	Lack of technological experience; activity may be pH sensitive	No
Chloramines	No	Mediocre bactericide, poor virucide	No[b]
Ferrate	Yes	Moderate bactericide; good virucide; residual unstable; lack of technological experience	No
High pH conditions	No	Poor biocide	No
Hydrogen peroxide	No	Poor biocide	No
Ionizing radiation	Yes	Lack of technological experience	No
Potassium permanganate	No	Poor biocide	No
Silver	No	Poor biocide; MCL 0.05 mg/liter	No
UV light	Yes	Adequate biocide; no residual; use limited by equipment maintenance considerations	No

[a] This evaluation relates solely to the suitability for controlling infectious disease transmission
[b] Chloramines may have use as a secondary disinfectant in the distribution system in view of their persistence.

Table 11.

Effect of Temperature on Rate of Inactivation of *E. coli* by Chlorine Dioxide[29]

Temperature °C	Chlorine Dioxide conc. (mg/L)	Contact Time (min)	C·t'[a]
5	0.30	1.8	0.54
15	0.30	1.3	0.39
25	0.30	0.98	0.29

[a] Chlorine dioxide concentration times contact time for 99% inactivation.

Table 12.

Inactivation of Microorganisms by Free Chlorine Species

Test Microorganism	Free Chlorine Species	pH	Temp. (°C)	Conc.	Contact Time (min)	C·t'[a]	Reference
E. coli	HOCl	6.0	5	0.1	0.4	0.04	31
	OCl^-	10.0	5	1.0	0.92	0.92	31
poliovirus 1	HOCl	6.0	5	0.5	2.1	1.05	32
	OCl^-	10.0	5	0.5	21	10.5	32
E. histolytica (cysts)	HOCl	6.0	5	5.0	18	90	33
G. lamblia (cysts)	HOCl	6.0	5	2.0	40	80	34

[a] Concentration times contact time for 99% inactivation

Table 13.

Inactivation of Microorganisms by Inorganic Chloramines

Test Microorganism	Combined Chlorine Species	pH	Temp. (°C)	Conc.	Contact Time (min)	C·t'[a]	Reference
E. coli	NH_2Cl	9.0	5	1.0	175	175	35
	NH_2Cl	9.0	15	1.0	64	64	35
	$NHCl_2$	4.5	15	1.0	5.5	5.5	36
Poliovirus 1	NH_2Cl	9.0	15	10	90	900	35
	$NHCl_2$	4.5	5	100	140	14,000	36
	$NHCl_2$	4.5	15	100	50	5,000	36
G. lamblia (cysts)	NH_2Cl/ $NHCl_2$	7.5	3	2.4	220	528	37

[a] Concentration times contact time for 99% inactivation

Table 14.

Inactivation of Microorganisms by Chlorine Dioxide[29]

Test Microorganisms	pH	Temp (C)	Conc. (mg/L)	Contact Time (min)	C.t'[a]
E. coli	7.0	5	0.30	1.8	0.54
Poliovirus 1	7.0	5	0.5	12.0	6.0
	7.0	21	0.3	5.0	1.5
	9.0	21	0.4	1.0	0.4

[a] Concentration times contact time for 99% inactivation

Table 15.

Inactivation of Microorganisms by Ozone

Test Microorganisms	pH	Temp (C)	Conc. (mg/L)	Contact Time (min)	C.t'[a]	Reference
E. coli	7.2	1	0.07	0.083	0.006	39
	7.2	1	0.065	0.33	0.022	39
Poliovirus 1	7.2	5	0.15	1.47	0.22	40
G. muris cysts	7.0	5	0.15	12.9	1.94	41

[a] Concentration times contact time for 99% inactivation